

# Link layer, LANs: outline

6.1 introduction, services

6.2 error detection,  
correction

6.3 multiple access  
protocols

6.4 LANs

- addressing, ARP
- Ethernet
- switches
- VLANs

6.5 link virtualization:  
MPLS

6.6 data center  
networking

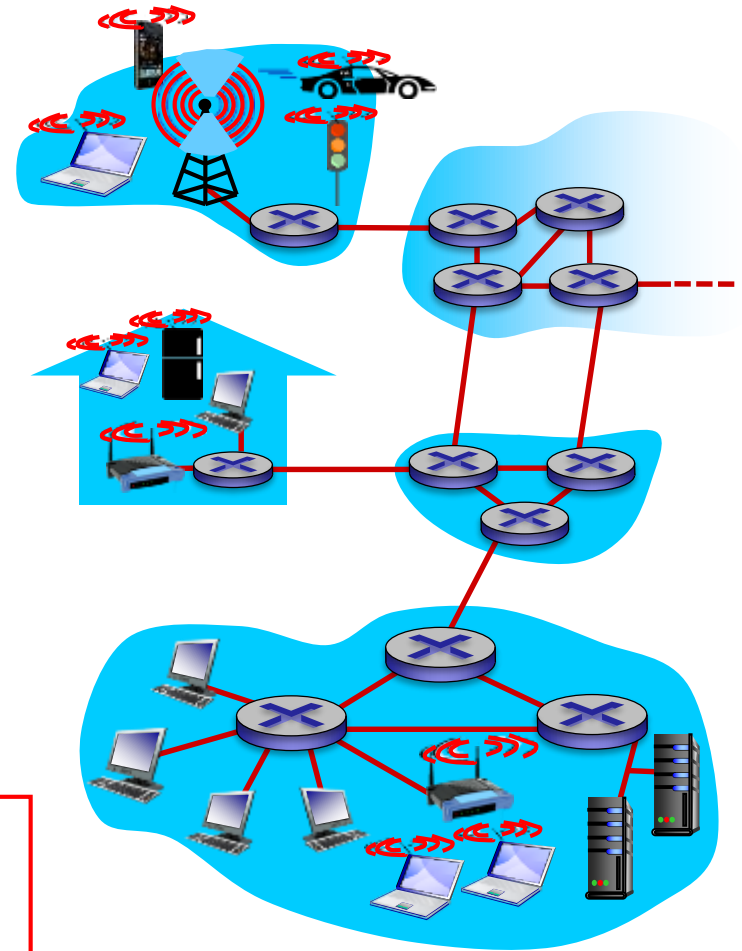
6.7 a day in the life of a  
web request

# Link layer: introduction

## *terminology:*

- hosts and routers: **nodes**
- communication channels that connect adjacent nodes along communication path: **links**
  - wired links
  - wireless links
  - LANs
- layer-2 packet: **frame**, encapsulates datagram

*data-link layer* has responsibility of transferring datagram from one node to *physically adjacent* node over a link



# Link layer: context

- datagram transferred by different link protocols over different links:
  - e.g., Ethernet on first link, frame relay on intermediate links, 802.11 on last link
- each link protocol provides different services
  - e.g., may or may not provide reliable data transfer over link

# Link layer services

## ■ *framing, link access:*

- encapsulate datagram into frame, adding header, trailer
- channel access if shared medium
- “MAC” addresses used in frame headers to identify source, destination
  - different from IP address!

## ■ *reliable delivery between adjacent nodes*

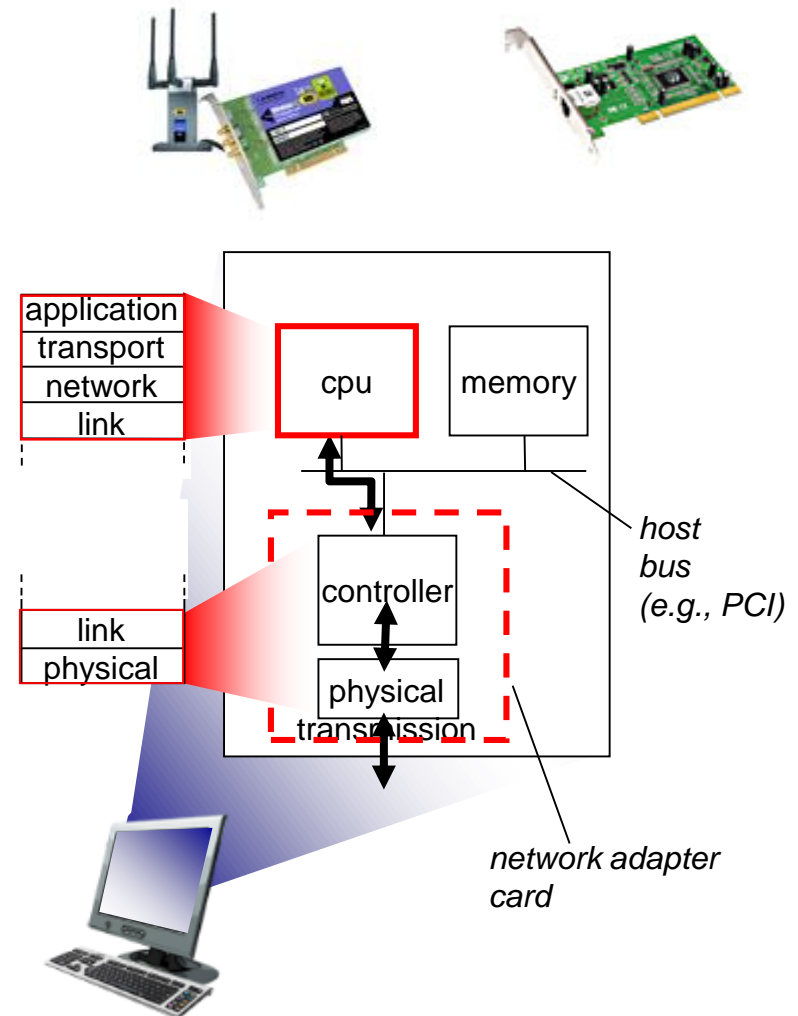
- we learned how to do this already (chapter 3)!
- seldom used on low bit-error link (fiber, some twisted pair)
- wireless links: high error rates

# Link layer services (more)

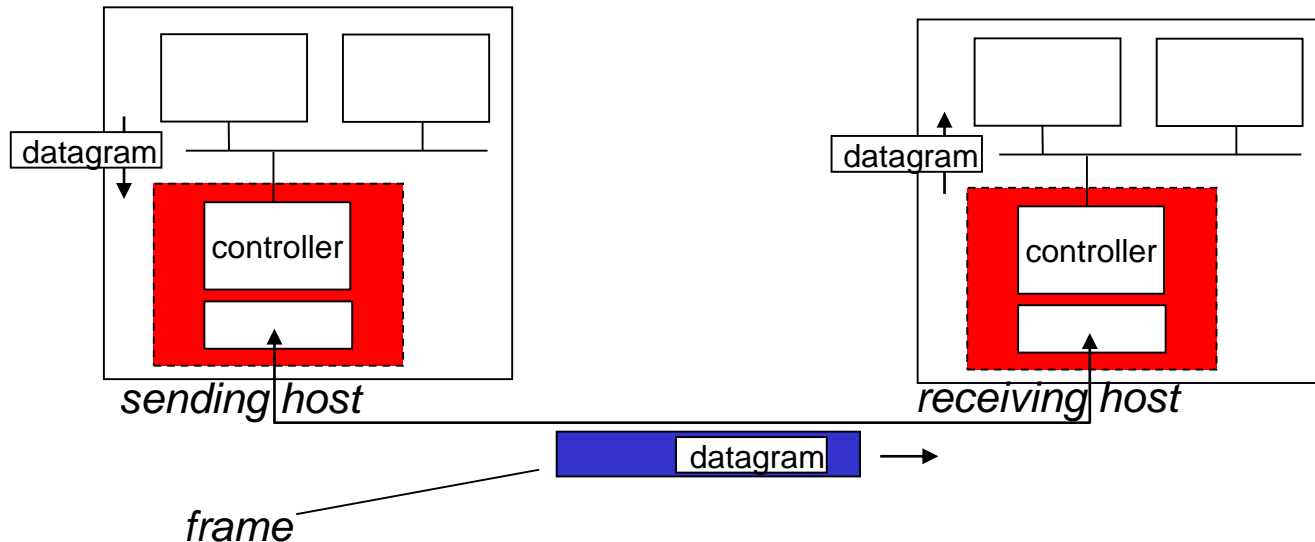
- *flow control:*
  - pacing between adjacent sending and receiving nodes
- *error detection:*
  - errors caused by signal attenuation, noise.
  - receiver detects presence of errors:
    - signals sender for retransmission or drops frame
- *error correction:*
  - receiver identifies *and corrects* bit error(s) without resorting to retransmission
- *half-duplex and full-duplex*
  - with half duplex, nodes at both ends of link can transmit, but not at same time

# Where is the link layer implemented?

- in each and every host
- link layer implemented in “adaptor” (aka *network interface card* NIC) or on a chip
  - Ethernet card, 802.11 card; Ethernet chipset
  - implements link, physical layer
- attaches into host's system buses
- combination of hardware, software, firmware



# Adaptors communicating



- sending side:
  - encapsulates datagram in frame
  - adds error checking bits, rdt, flow control, etc.
- receiving side
  - looks for errors, rdt, flow control, etc.
  - extracts datagram, passes to upper layer at receiving side

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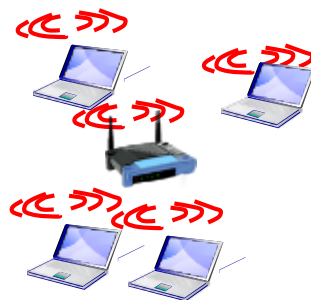
# Multiple access links, protocols

two types of “links”:

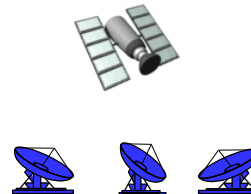
- point-to-point
  - PPP for dial-up access
  - point-to-point link between Ethernet switch, host
- *broadcast (shared wire or medium)*
  - old-fashioned Ethernet
  - upstream HFC
  - 802.11 wireless LAN



shared wire (e.g.,  
cabled Ethernet)



shared RF  
(e.g., 802.11 WiFi)



shared RF  
(satellite)



humans at a  
cocktail party  
(shared air, acoustical)

# Multiple access protocols

- single shared broadcast channel
- two or more simultaneous transmissions by nodes:  
interference
  - *collision* if node receives two or more signals at the same time

## *multiple access protocol*

- distributed algorithm that determines how nodes share channel, i.e., determine when node can transmit
- communication about channel sharing must use channel itself!
  - no out-of-band channel for coordination

# An ideal multiple access protocol

*given:* broadcast channel of rate  $R$  bps

*Desired properties:*

1. when one node wants to transmit, it can send at rate  $R$ .
2. when  $M$  nodes want to transmit, each can send at average rate  $R/M$
3. fully decentralized:
  - no special node to coordinate transmissions
  - no synchronization of clocks, slots
4. simple

# MAC protocols: taxonomy

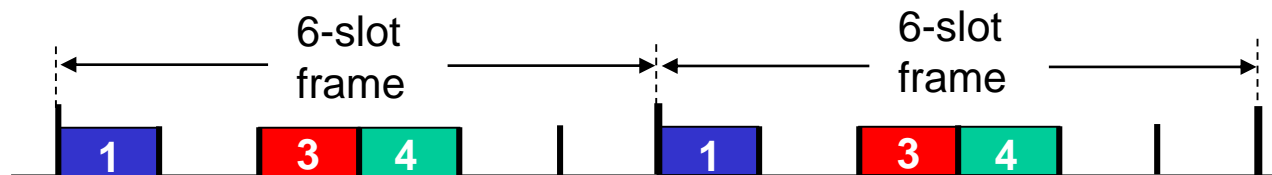
three broad classes:

- *channel partitioning*
  - divide channel into smaller “pieces” (time slots, frequency, code)
  - allocate piece to node for exclusive use
- *random access*
  - channel not divided, allow collisions
  - “recover” from collisions
- *“taking turns”*
  - nodes take turns, but nodes with more to send can take longer turns

# Channel partitioning MAC protocols: TDMA

## TDMA: time division multiple access

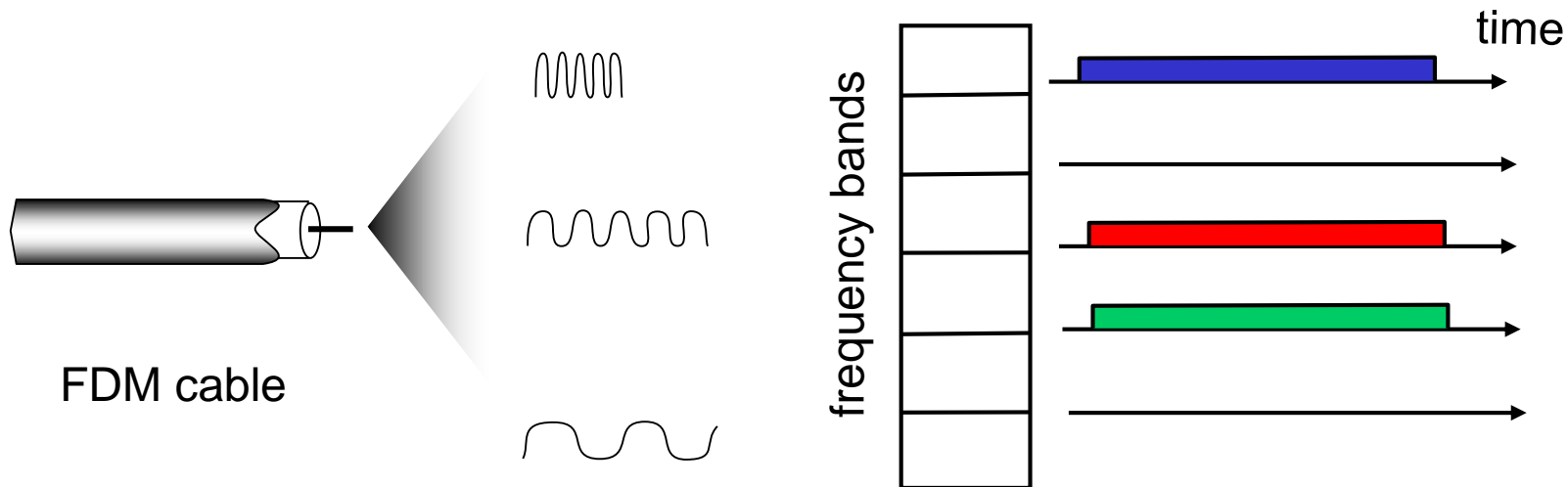
- access to channel in "rounds"
- each station gets fixed length slot (length = packet transmission time) in each round
- unused slots go idle
- example: 6-station LAN, 1,3,4 have packets to send, slots 2,5,6 idle



# Channel partitioning MAC protocols: FDMA

## FDMA: frequency division multiple access

- channel spectrum divided into frequency bands
- each station assigned fixed frequency band
- unused transmission time in frequency bands go idle
- example: 6-station LAN, 1,3,4 have packet to send, frequency bands 2,5,6 idle



# Random access protocols

- when node has packet to send
  - transmit at full channel data rate  $R$ .
  - no *a priori* coordination among nodes
- two or more transmitting nodes → “collision”,
- **random access MAC protocol** specifies:
  - how to detect collisions
  - how to recover from collisions (e.g., via delayed retransmissions)
- examples of random access MAC protocols:
  - slotted ALOHA
  - ALOHA
  - CSMA, CSMA/CD, CSMA/CA

# Slotted ALOHA

## *assumptions:*

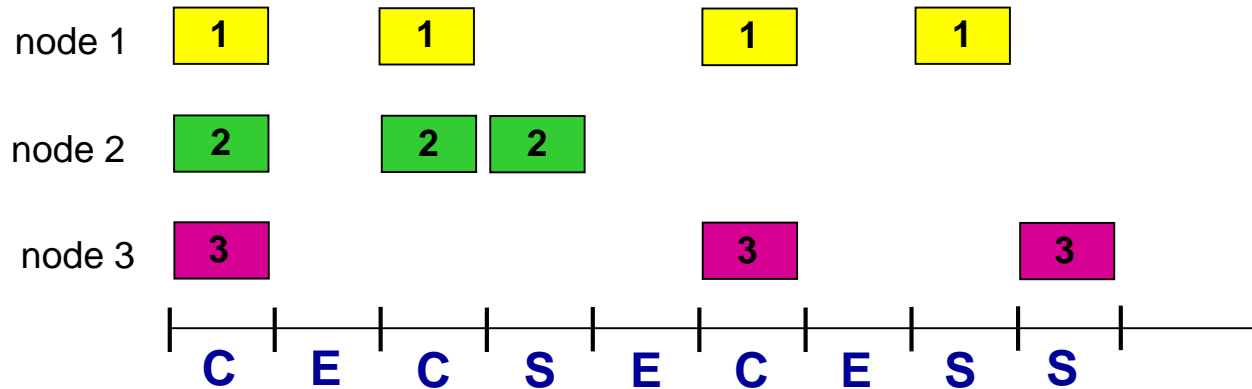
- all frames same size
- time divided into equal size slots (time to transmit 1 frame)
- nodes start to transmit only slot beginning
- nodes are synchronized
- if 2 or more nodes transmit in slot, all nodes detect collision

## *operation:*

- when node obtains fresh frame, transmits in next slot
  - *if no collision:* node can send new frame in next slot
  - *if collision:* node retransmits frame in each subsequent slot with prob.  $p$  until success



# Slotted ALOHA



## *Pros:*

- single active node can continuously transmit at full rate of channel
- highly decentralized: only slots in nodes need to be in sync
- simple

## *Cons:*

- collisions, wasting slots
- idle slots
- nodes may be able to detect collision in less than time to transmit packet
- clock synchronization

# Slotted ALOHA: efficiency

**efficiency:** long-run fraction of successful slots (many nodes, all with many frames to send)

- suppose:  $N$  nodes with many frames to send, each transmits in slot with probability  $p$
- prob that given node has success in a slot =  $p(1-p)^{N-1}$
- prob that *any* node has a success =  $Np(1-p)^{N-1}$

- max efficiency: find  $p^*$  that maximizes  $Np(1-p)^{N-1}$
- for many nodes, take limit of  $Np^*(1-p^*)^{N-1}$  as  $N$  goes to infinity, gives:

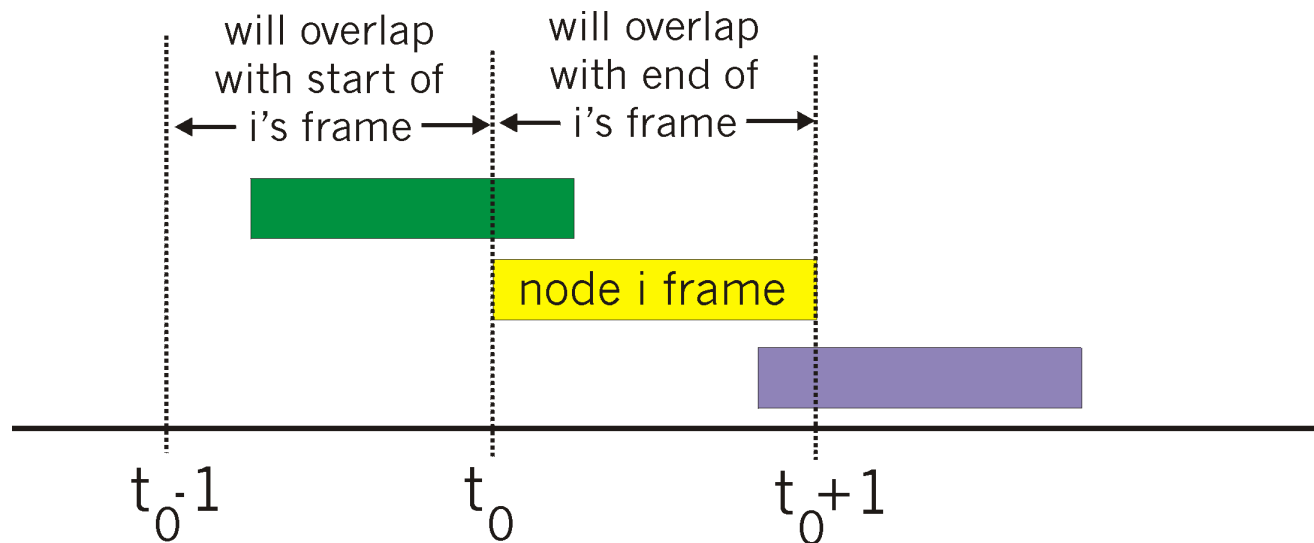
$$\text{max efficiency} = 1/e = .37$$

**at best:** channel used for useful transmissions 37% of time!



# Pure (unslotted) ALOHA

- unslotted Aloha: simpler, no synchronization
- when frame first arrives
  - transmit immediately
- collision probability increases:
  - frame sent at  $t_0$  collides with other frames sent in  $[t_0 - 1, t_0 + 1]$



# Pure ALOHA efficiency

$P(\text{success by given node}) = P(\text{node transmits}) \cdot$

$P(\text{no other node transmits in } [t_0-1, t_0]) \cdot$

$P(\text{no other node transmits in } [t_0-1, t_0])$

$$= p \cdot (1-p)^{N-1} \cdot (1-p)^{N-1}$$

$$= p \cdot (1-p)^{2(N-1)}$$

... choosing optimum  $p$  and then letting  $n \rightarrow \infty$

$$= 1/(2e) = .18$$

**even worse than slotted Aloha!**

# CSMA (carrier sense multiple access)

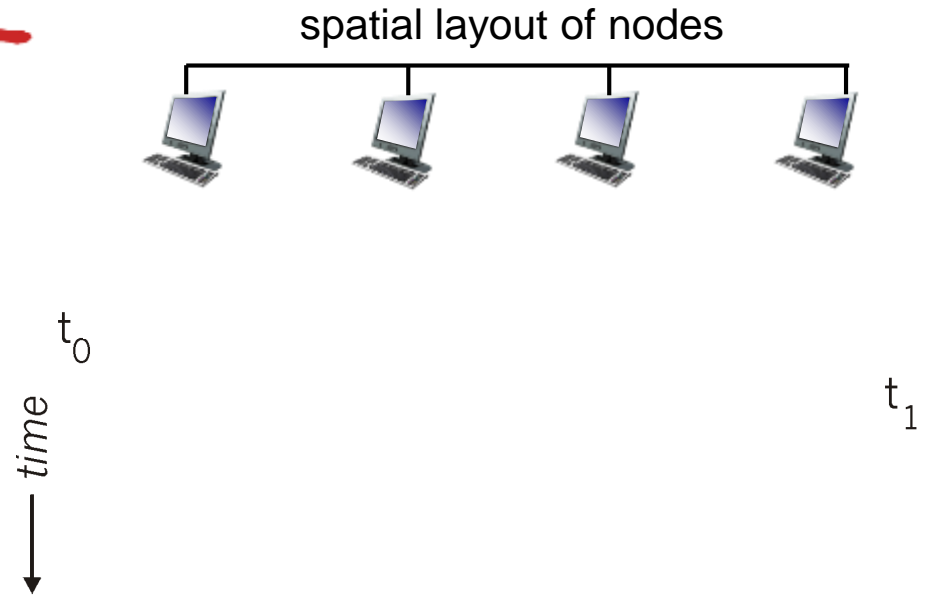
**CSMA:** listen before transmit:

if channel sensed idle: transmit entire frame

- if channel sensed busy, defer transmission
- human analogy: don't interrupt others!

# CSMA collisions

- **collisions can still occur:** propagation delay means two nodes may not hear each other's transmission
- **collision:** entire packet transmission time wasted
  - distance & propagation delay play role in determining collision probability

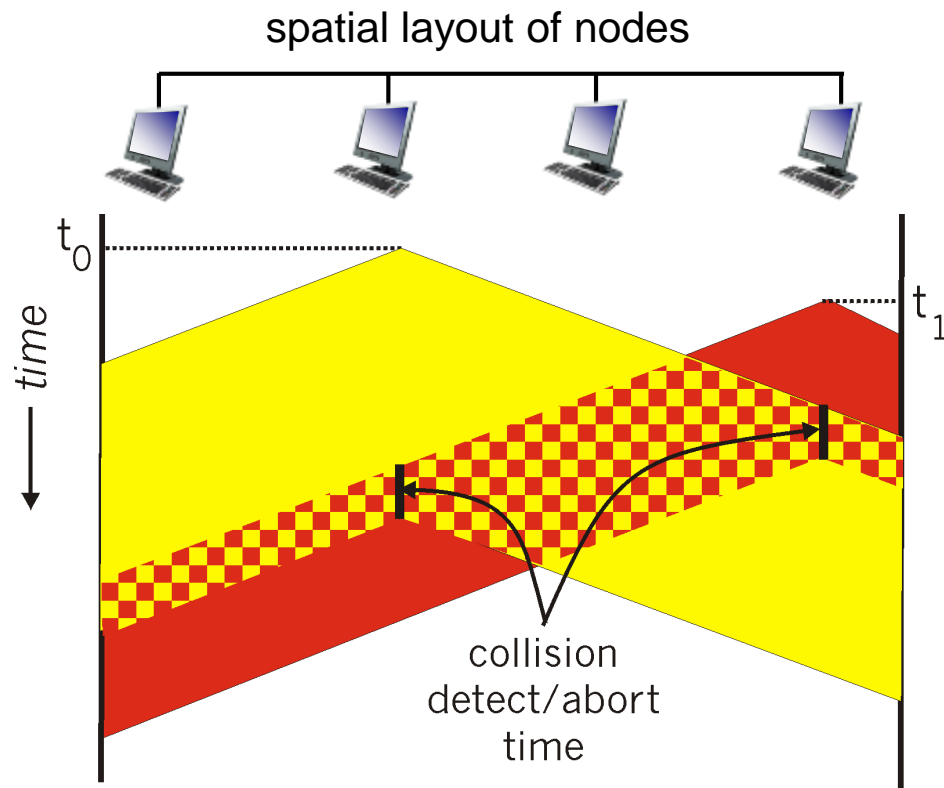


# CSMA/CD (collision detection)

**CSMA/CD:** carrier sensing, deferral as in CSMA

- collisions *detected* within short time
- colliding transmissions aborted, reducing channel wastage
- collision detection:
  - easy in wired LANs: measure signal strengths, compare transmitted, received signals
  - difficult in wireless LANs: received signal strength overwhelmed by local transmission strength
- human analogy: the polite conversationalist

# CSMA/CD (collision detection)





# “Taking turns” MAC protocols

## channel partitioning MAC protocols:

- share channel *efficiently* and *fairly* at high load
- inefficient at low load: delay in channel access,  $1/N$  bandwidth allocated even if only 1 active node!

## random access MAC protocols

- efficient at low load: single node can fully utilize channel
- high load: collision overhead

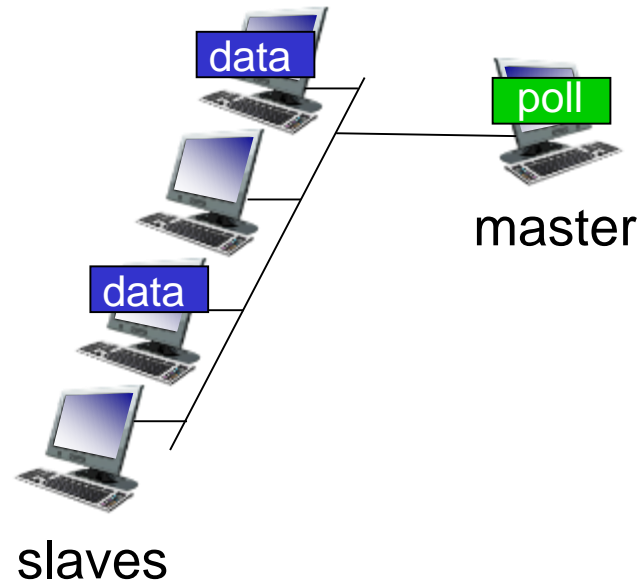
## “taking turns” protocols

look for best of both worlds!

# “Taking turns” MAC protocols

## *polling:*

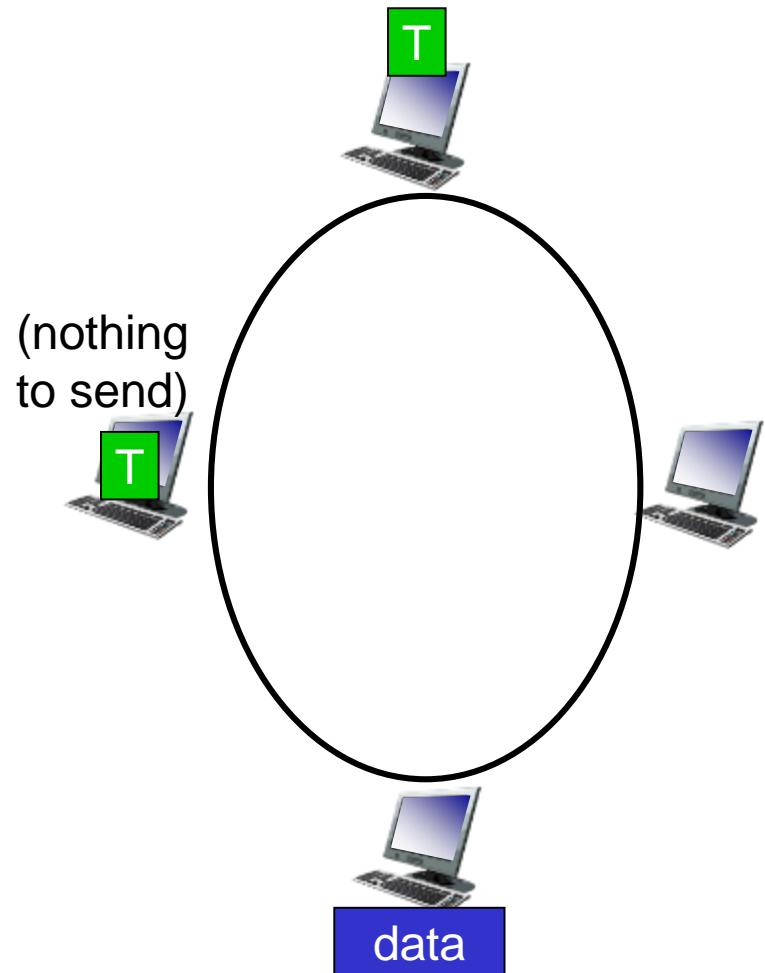
- master node “invites” slave nodes to transmit in turn
- typically used with “dumb” slave devices
- concerns:
  - polling overhead
  - latency
  - single point of failure (master)



# “Taking turns” MAC protocols

## token passing:

- control *token* passed from one node to next sequentially.
- token message
- concerns:
  - token overhead
  - latency
  - single point of failure (token)



# Summary of MAC protocols

- *channel partitioning*, by time, frequency or code
  - Time Division, Frequency Division
- *random access* (dynamic),
  - ALOHA, S-ALOHA, CSMA, CSMA/CD
  - carrier sensing: easy in some technologies (wire), hard in others (wireless)
  - CSMA/CD used in Ethernet
  - CSMA/CA used in 802.11
- *taking turns*
  - polling from central site, token passing
  - Bluetooth, FDDI, token ring

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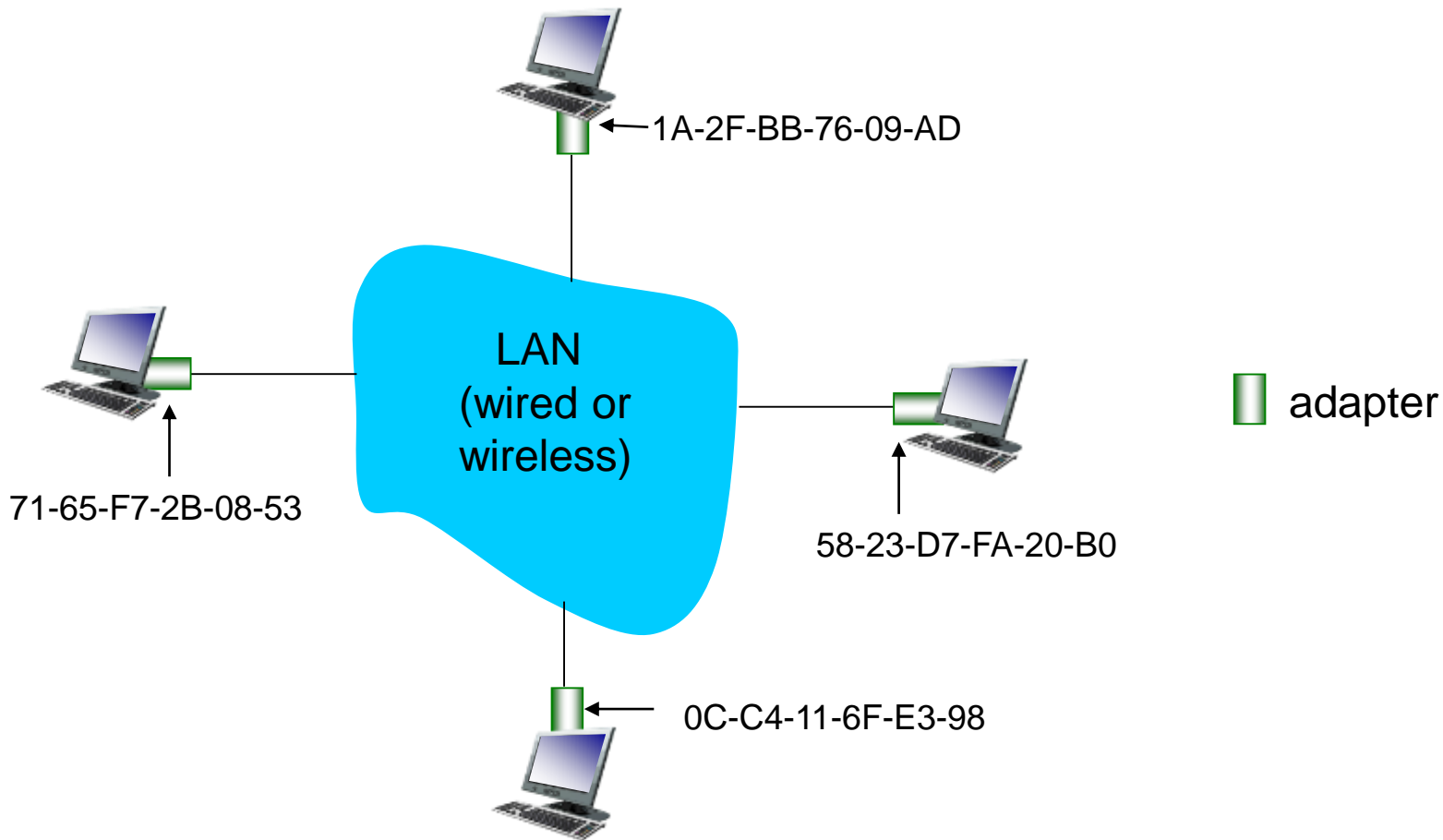
# MAC addresses and ARP

- 32-bit IP address:
  - *network-layer* address for interface
  - used for layer 3 (network layer) forwarding
- MAC (or LAN or physical or Ethernet) address:
  - function: *used ‘locally’ to get frame from one interface to another physically-connected interface (same network, in IP-addressing sense)*
  - 48 bit MAC address (for most LANs) burned in NIC ROM, also sometimes software settable
  - e.g.: 1A-2F-BB-76-09-AD

hexadecimal (base 16) notation  
(each “numeral” represents 4 bits)

# LAN addresses and ARP

each adapter on LAN has unique **LAN** address



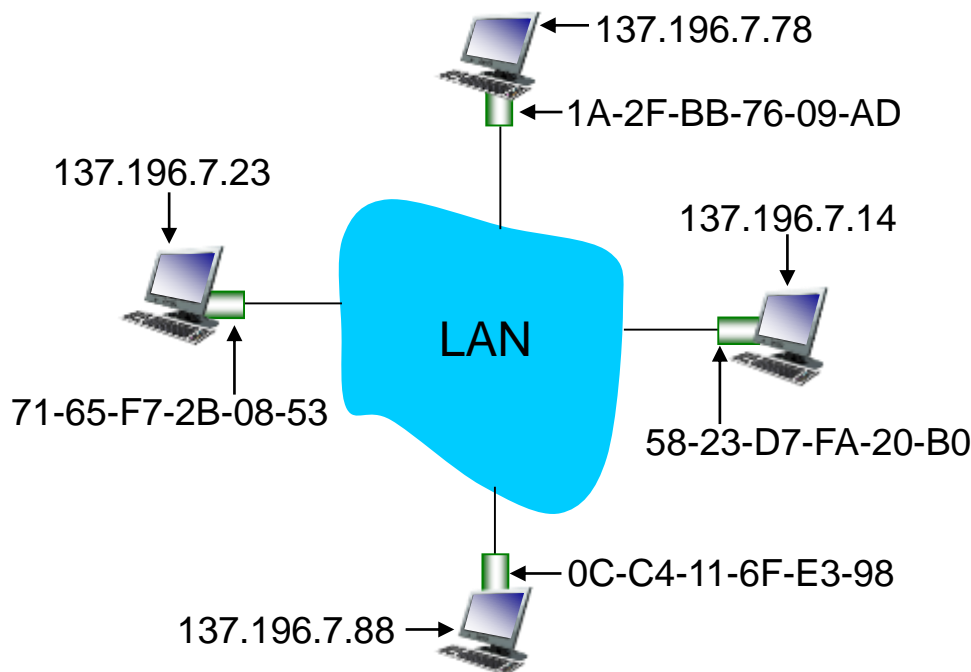
# LAN addresses (more)

- MAC address allocation administered by IEEE
- manufacturer buys portion of MAC address space (to assure uniqueness)
- analogy:
  - MAC address: like Social Security Number
  - IP address: like postal address
- MAC flat address → portability
  - can move LAN card from one LAN to another
- IP hierarchical address *not* portable
  - address depends on IP subnet to which node is attached



# ARP: address resolution protocol

**Question:** how to determine interface's MAC address, knowing its IP address?



**ARP table:** each IP node (host, router) on LAN has table

- IP/MAC address mappings for some LAN nodes:  
< IP address; MAC address; TTL >
- TTL (Time To Live): time after which address mapping will be forgotten (typically 20 min)

# ARP protocol: same LAN

- A wants to send datagram to B
  - B's MAC address not in A's ARP table.
- A **broadcasts** ARP query packet, containing B's IP address
  - destination MAC address = FF-FF-FF-FF-FF-FF
  - all nodes on LAN receive ARP query
- B receives ARP packet, replies to A with its (B's) MAC address
  - frame sent to A's MAC address (unicast)
- A caches (saves) IP-to-MAC address pair in its ARP table until information becomes old (times out)
  - soft state: information that times out (goes away) unless refreshed
- ARP is “plug-and-play”:
  - nodes create their ARP tables *without intervention from net administrator*